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# Power Reduction in OFDM based Cognitive Radio Systems

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***Abstract*— The increasing demand for wireless communication introduces efficient spectrum utilization challenge. To address this challenge, cognitive radio has emerged as the key technology, which enables opportunistic access to the spectrum. The main potential advantages introduced by cognitive radio are improving spectrum utilization and increasing communication quality. In this paper, we consider the high peak-to-average power ratio (PAPR) problem of orthogonal frequency division multiplexing (OFDM) signals in cognitive radio systems. A high PAPR can lead to saturation in the power amplifier (PA) of secondary users (SUs) and consequently increase spectral spreading, and cause interference to adjacent primary users (PUs).Simulation results illustrates the performance of the system under Additive White Gaussian Noise (AWGN) and further evaluation is done for comparing the proposed companding technique with previous techniques. The power spectral density (PSD) and bit error rate (BER) are evaluated at the output of the nonlinear PAs to provide a realistic performance comparison.**

***Keywords- Cognitive radio; Orthogonal frequency division multiplexing ; Additive White Gaussian Noise.***

## I. INTRODUCTION

Orthogonal Frequency Division Multiplexing (OFDM) has significant ability to support high data rates for wide area coverage, robustness to multipath fading, immunity to impulse interference [1,2]. Due to the rapid development of wireless communications in recent years, the demand on wireless spectrum has been growing dramatically, resulting in the spectrum scarcity problem. Works have shown that the fixed spectrum allocation policy commonly adopted today suffer from the low spectrum utilization problem. However one of the major drawbacks of OFDM signal is its large envelope fluctuation, likely resulting in large peak-to average power ratio (PAPR), which distorts the signal if the transmitter contains the non-linear components such as power amplifiers and these may causes deficiencies such as inter modulation, spectral spreading and change in signal constellation. Cognitive radio, with the capability to flexibly adapt its parameters, has been proposed as the enabling technology for unlicensed secondary users to dynamically access the licensed spectrum owned by legacy primary users on a negotiated or an opportunistic basis.

The paper is organized as follows: the PAPR problem in OFDM is briefly reviewed in section II. Section III, presents OFDM based CR to reduce the PAPR .In Section IV, the performance of proposed algorithm is compared with existing techniques. In Section V, we conclude.

## II. PAPR IN OFDM

Let $X(0),X(1),\cdots,X(N-1)$ represent the data sequence to be transmitted in an OFDM symbol with $N$ subcarriers. The basic OFDM transmitter and receiver are shown in fig.1. ,The baseband representation of the OFDM symbol is given by:

$$x(t)=\frac{1}{\sqrt{N}}\sum_{n=0}^{N-1}X(n)e^{j2\pi nt/N},0\le t\le T \qquad (1)$$

where x(t) is OFDM symbol at time t,$T$ is the duration of the OFDM symbol.

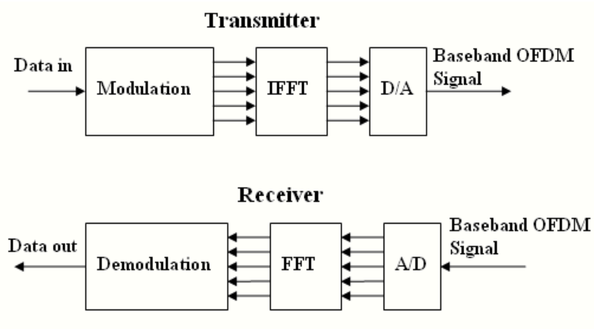


Figure 1. Basic OFDM Transmitter and Receiver

The input information symbols are assumed to be statistically independent and identically distributed. According to the central limit theorem, when $N$ is large, both the real and imaginary parts of $x(t)$ becomes Gaussian distribution, each with zero mean and a variance of $E[|x(t)|^2]/2$ , The amplitude, or modulus, of OFDM signal is given by

$$x_t=\sqrt{\mathrm{Re}^2\{x_t\}+\mathrm{Im}^2\{x_t\}} \qquad (2)$$

The power of OFDM signal can be calculated as

$$|x_t|^2=\frac{1}{\sqrt{N}}\sum_{m=0}^{N-1}\sum_{k=0}^{N-1}X_m X_k\frac{\exp(j2\pi(m-k)t}{N} \qquad (3)$$

Where, m=0,1,….N-1,k=0,1…N-1.Consequently it is possible that the maximum amplitude of OFDM signal may well exceed its average amplitude. Practical hardware (e.g. A/D and D/A converters, power amplifiers) has finite dynamic range; therefore the peak amplitude of OFDM signal must be limited.

The PAPR of the over sampled OFDM signal is mathematically defined as:

$$PAPR = 10\log_{10}\left\{\frac{p_{\max}}{p_{avg}}\right\} = 10\log_{10}\frac{\max\left[\left|x(t)\right|^2\right]}{\frac{1}{NT}\int_0^T \left|x(t)\right|^2 dt}(dB) \tag{4}$$

The peak power occurs when modulated symbols are added with the same phase. The effectiveness of a PAPR reduction technique is measured by the complementary cumulative distribution function (CCDF), which is the probability that PAPR exceeds some threshold [11,12], i.e.

$$\mathrm{CCDF} = \mathrm{Probability}(\mathrm{PAPR} > \mathrm{PAPR}_0) \tag{5}$$

Where, $PAPR_0$ is the threshold level.

Moreover with the increase of number of subcarriers,Papr of the resulting system also increases .The reason forthis is that when the number of subcarriers is large and they are all added in some positive or negative phases ,the resulting amplitude becomes large enough to exceed saturation point of high power amplifier(HPA). Fig .2 shows such situation.

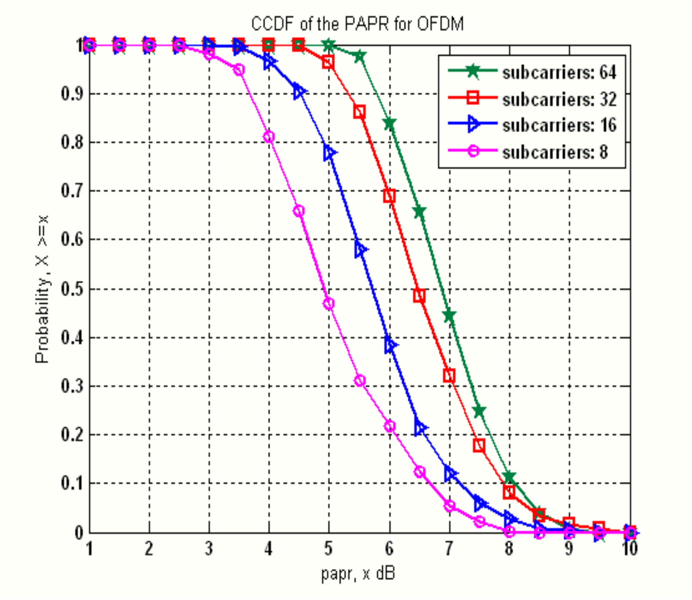


Figure 2. Illustration of effect of number of subcarriers on PAPR

The next section describes the cognitive radio based orthogonal frequency division multiplexing.

## III. WHY OFDM IS A GOOD FIT FOR CR

OFDM's underlying sensing and spectrum shaping capabilities together with its flexibility and adaptivity make it probably the best transmission technology for CR systems. In the following, we present some of the requirements for CR and explain how OFDM can fulfill these requirements. A summary of these requirements and strength of OFDM in meeting them are presented in Table I.

TABLE I. CR REQUIREMENTS AND OFDM STRENGTH

| S. No. | CR Requirements | OFDM's Strength |
|---|---|---|
| 1 | Spectrum sensing | Inherent FFT operation of OFDM eases spectrum sensing in frequency domain. |
| 2 | Efficient spectrum utilization | Waveform can easily be shaped by simply turning off some subcarriers where primary users exist. |
| 3 | Adaptation/Scalability | OFDM systems can be adapted to different transmission environments and available resources. Some adaptable parameters are FFT size, subcarrier spacing, CP size, modulation, coding, sub-carrier powers. |
| 4 | Advanced antenna techniques | Techniques such as multiple-input multiple-output (MIMO) are commonly used with OFDM mainly because of the reduced equalizer complexity. OFDM also supports smart antennas |

Next we examine the BER performance of the proposed algorithm. Let y($t$) denote the output signal of the compander, w($t$) the white Gaussian noise. The received signal can be expressed as:

$$z(t) = y(t) + w(t) \tag{6}$$

The decompanded signal $\bar{x}(t)$ simply is:

$$\bar{x}(t) = f^{-1}[z(t)] = f^{-1}[y(t) + w(t)] \tag{7}$$

It is worth to mention that BER and PAPR affect each other adversely and therefore there is a tradeoff.

TABLE II. NUMERICAL RESULTS

The performance of the proposed OFDM system architecture (Fig.1) is evaluated with Complimentary Cumulative Distribution Function (CCDF) of new companding technique. Some of the simulation parameters are listed in Table 2.

TABLE III. LIST OF OFDM PARAMETERS

| | |
|---|---|
| Number of Transmit antenna | 1 |
| Number of Receive antenna | 1 |
| Number of Data streams | 1 |
| FFT Size | 128 |
| Number of Subcarriers | 8 |
| Channel model | Additive White Gaussian Noise |
| Modulation | QPSK |

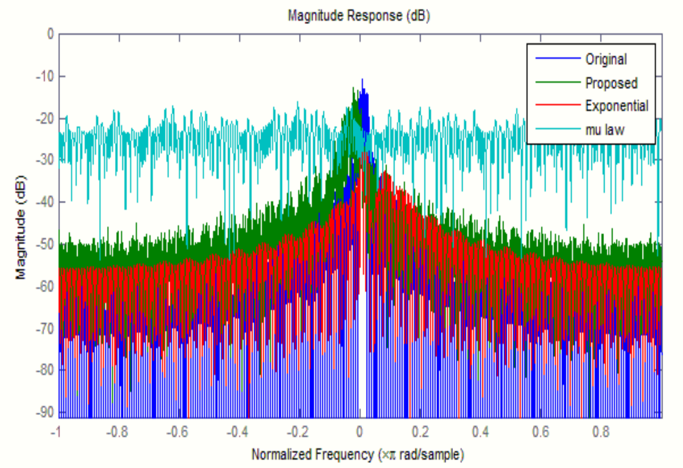


Figure 3. Power spectral density of original and companded signals

Fig.2. Illustrates the effect of number of subcarriers on PAPR with FFT size fixed at 128.The spectrums of the uncompressed and compressed OFDM signals by the proposed scheme are illustrated in Fig.3.From the simulation results; it is observed that the proposed algorithm produces OBI almost 3dB lower than the exponential algorithm, 10dB lower than the $\mu$-law. The BER vs. SNR is plotted in Fig.4 proposed algorithm has improved bit error rate compared with exponential and μ-law algorithms. The amount of improvement increases as SNR becomes more.

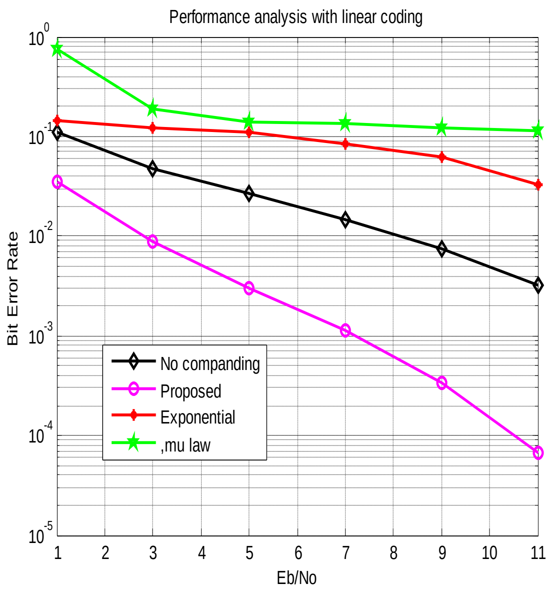


Figure 4. BER Vs SNR for original and companded signals in AWGN channel

## IV. CONCLUSION

A novel companding algorithm compared with all the previous techniques is proposed to effectively reduce PAPR problem in Orthogonal Frequency Division Multiplexing (OFDM) based cognitive radio systems .By careful selection of the control parameter α explained in the paper, the PAPR reduction can be achieved in a better way and the BER performance can be improved. Simulation results show, that the proposed algorithm offers improved performance in terms of BER and OBI while reducing PAPR effectively compared with exponential and μ-law companding schemes.

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